The Impact of the Assimilation of AIRS Radiance Measurements on Short-term Weather Forecasts

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Brief Update on AIRS Profile Assimilation Work at SPoRT

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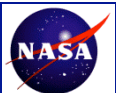
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NASA/MSFC Short Term Prediction Research and Transition (SPoRT) Center

16 April 2008

transitioning unique NASA data and research technologies
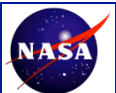
Improved Weather Forecasts with AIRS Data

WHY
Weather forecasting is an initial value problem – the better you represent the atmosphere / surface in the initial conditions, the better the forecast.

- The utilization of advanced remote sensing capabilities within a numerical weather prediction system is a massive task

- At the very core of numerical weather prediction, data assimilation is the discipline of incorporating as much information as possible to best characterize an atmospheric state for model initialization

- Much of the research in the field stems from operational centers, including NOAA/NCEP/EMC, ECMWF, Meteo France, CMC, UKMET, JMA

- There are, however, many research-tasked centers and universities that also have significant DA components/programs, including *NASA-SPoRT*, NASA-GMAO, *JCSDA*, Univ. of Maryland-College Park, UCAR, *UAH*

- Part of the problem with utilizing new systems is the concept of *transition*, or moving the research into operations
  - life span of instrument

- Groups like SPoRT and JCSDA have been created with the specific task of aiding in transition

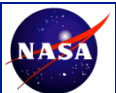*transitioning unique NASA data and research technologies*

Data Assimilation

The Concept of Data Assimilation in a Modeling Framework is Simple

- **Optimally blend <u>observations</u> to determine an estimation of the initial state of the atmosphere, or in simpler terms, create an analysis**
- **In numerical modeling, you need a three-dimensional analysis of every model variable of concern**
    - **Obviously we do not have measurements of every variable at every gridpoint in a model domain**
    - **Even if we did, they'd have errors associated with them**
- **Thus, a "first guess", or <u>background field</u>, is needed**
- **Therefore, data assimilation becomes an issue of not only blending the observations, but <u>blending the observation and a background field</u>**
- **Various methodologies exist to perform data assimilation**
    - **Historical: Objective Analysis (i.e. Barnes, Cressman), OI**
    - **Modern: Variational (<u>3D-Var</u>, 4D-Var), Various EnKF Formulations**

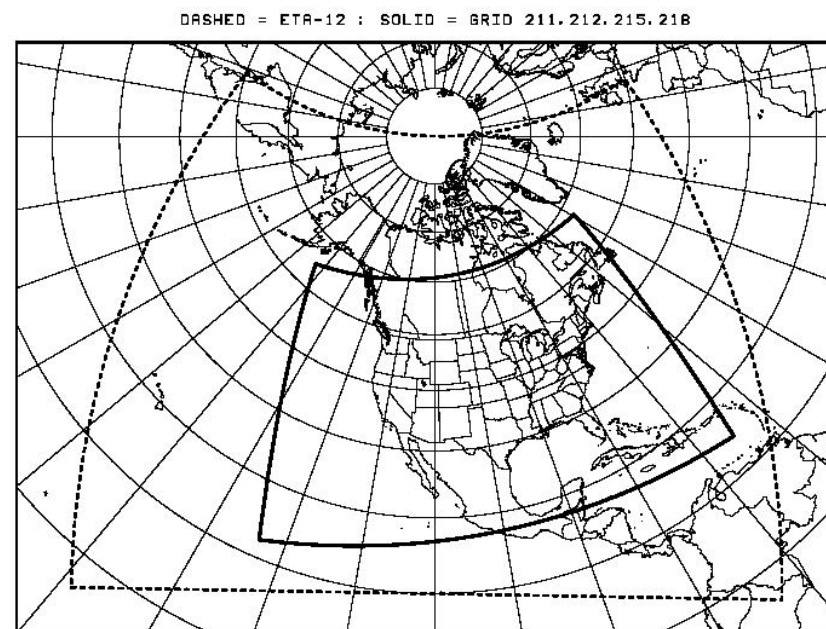# DA/Model System Setup

North American Model (NAM)

- The operational *regional* model at NCEP
- WRF-NMM dynamic core
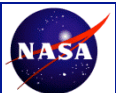- 12 km gridspacing, on NAM12 grid

NAM Data Assimilation System (NDAS)

- Gridpoint Statistical Interpolation (GSI) 3D-Var
  - Operational in NDAS, GDAS, Rapid Refresh, and GMAO
- In very simple terms, 3D-Var is the weighted mean between the background and the observations, minimizing the cost function:
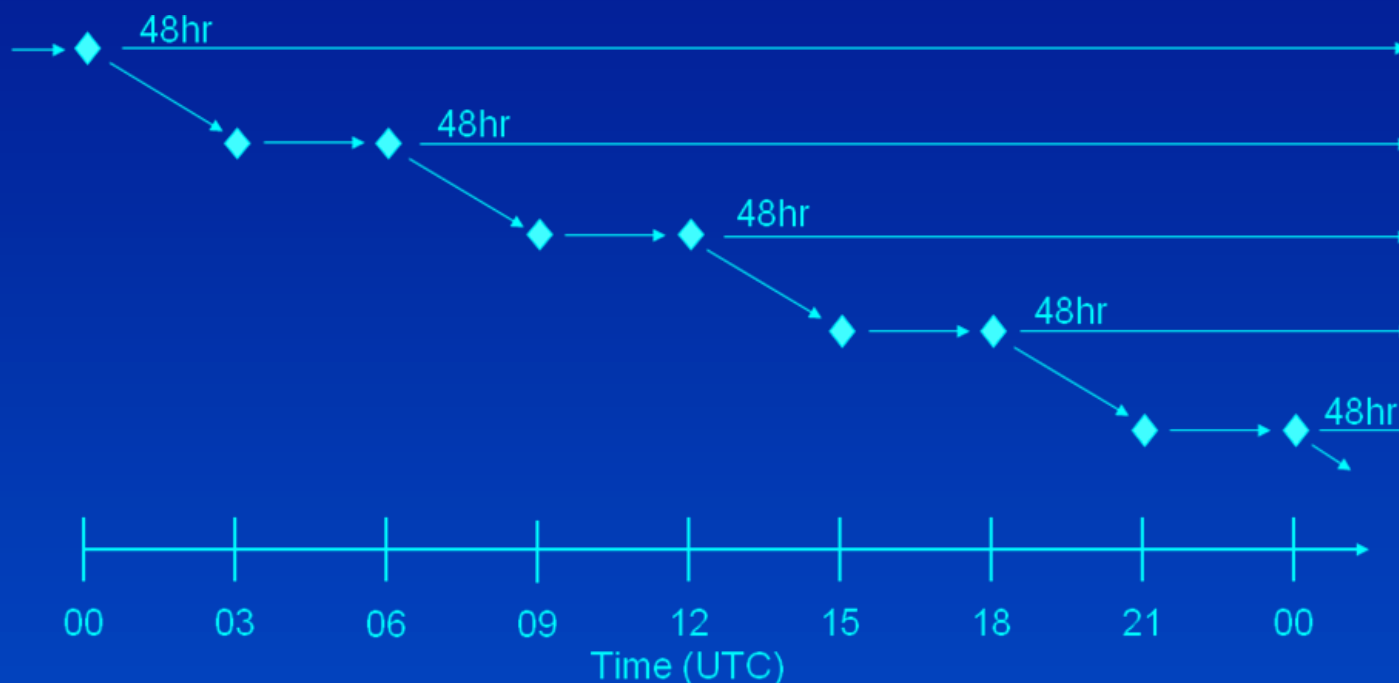

DASHED = ETA-12 ; SOLID = GRID 211.212.215.218

$$J(\delta x) = \delta x^T B^{-1} \delta x + \delta y^T R^{-1} \delta y$$
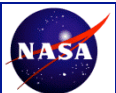$$\text{where } \delta y = y - H(x_a) = y - (H(x_b) + H\delta x)$$

SPORT

Experimental Design

Control (CNTL)

- All data used in the operational system, except Level-II radial winds
- *Conventional Observations*: Sonde, surface, aircraft
- *Unconventional Observations:*
  - *PREPBUFR:* Satellite derived winds, GOES-12 radiances
  - *External:*
    - Infrared Sounders: HIRS
    - Microwave Sounders: AMSU-A (Not Aqua), AMSU-B, MHS
    - NEXRAD Radar: Level II and Level III Radial wind super obs

AIRS Experiment

- All data used in the CNTL
- Atmospheric Infrared Sounder (AIRS) radiances are also assimilated
- Thinning:
  - 281 channels (red) distributed to operational centers in NRT
  - Formerly 1 of 3x3 footprints, NCEP now receives every footprint
  - In NAM assimilation, less than 0.1% of total global observations are used routinely
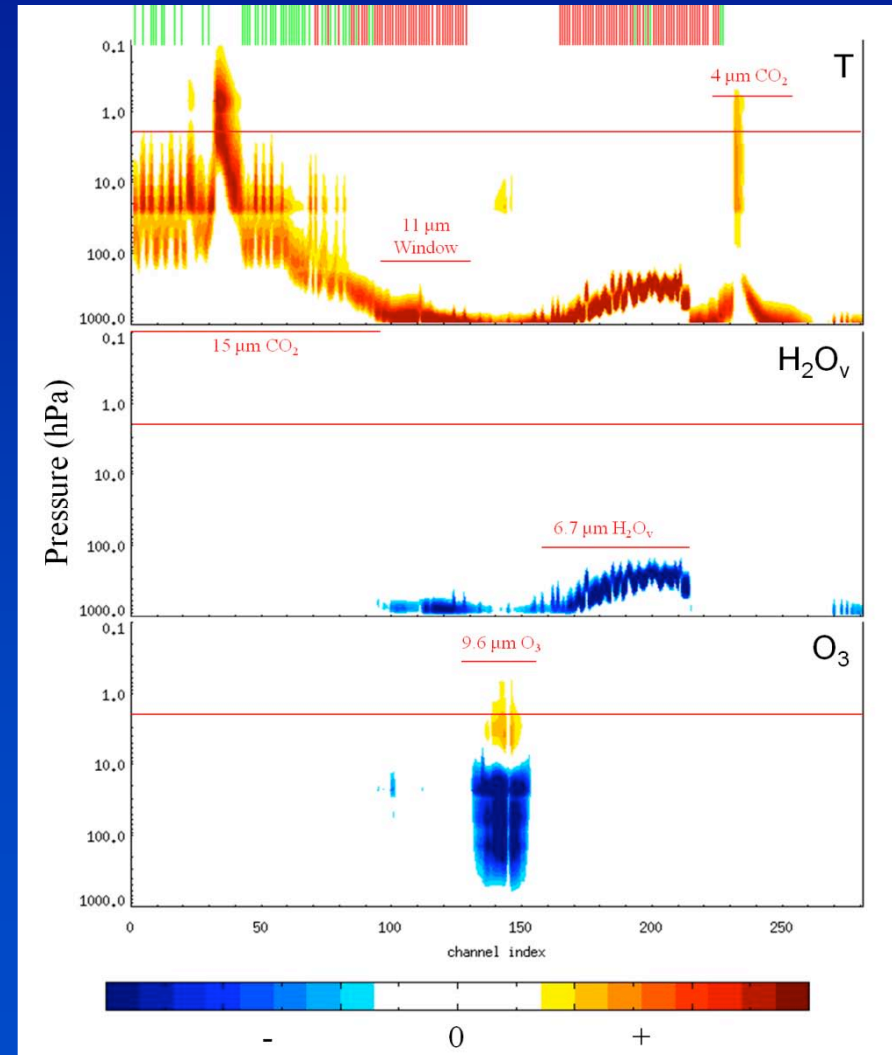
Atmospheric Infrared Sounder (AIRS)
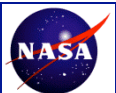
Channel Selection

- **Limited to 281 channels available for operational assimilation**

- **The brightness temperature sensitivity, as defined as**

$$\delta T_b^i = \frac{dT_b^i}{dq^i}(\delta q^i)$$

  are shown to the right

- **The NAM model top is at 2 hPa**

  - **Channels above this are inapplicable**

- **The NAM, unlike the GFS, has no O_3**

- **No 4µm channels are used**

- **Thus, of the 281 channels, 103 are selected for use (red)**

- **This is compared to 151 channels used in the global system (green, red inclusive)**

Results

Timeframe

- The two experiments (CNTL and AIRS) are shown
- The results shown are from forecasts spawned between 0000 UTC 09 Apr 2007 and 0000 UTC 16 Apr 2007
- Prior to this, the assimilation cycle is run for two weeks
  - Allows for stabilization of bias correction parameters and for negative impact occurring during this stabilization to propagate out of the domain
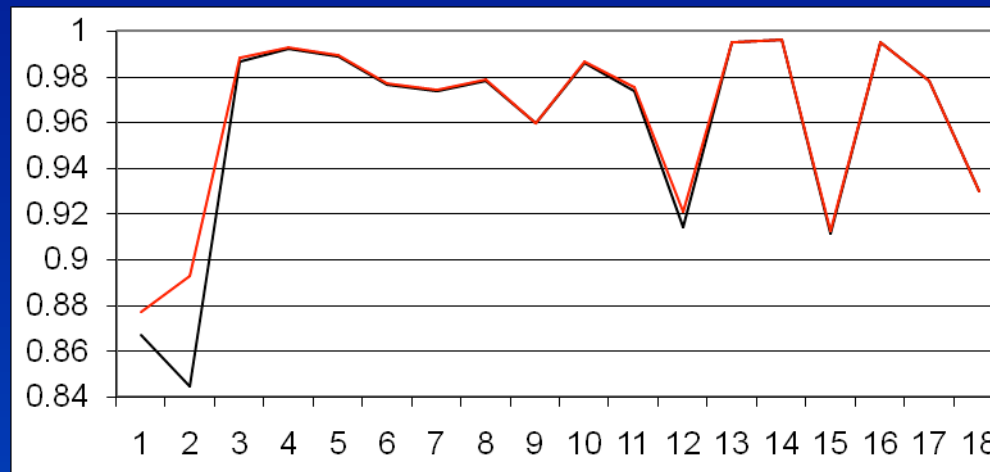 - Allows for impact of AIRS to propagate through the background field

Analysis Verification

- Verifying the analysis itself is difficult in that most validation sources are operationally assimilated, thus not independent
- One source of independent data is GOES-11 sounder measurements that, unlike GOES-12, are not assimilated operationally
- Analysis must then be <u>transformed to observation space</u> via the nonlinear *H* operator.
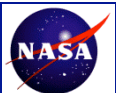 - Community Radiative Transfer Model (CRTM)

Analysis Verification

GOES-11 Brightness Temperatures

- The correlation between clear-sky observed brightness temperatures and brightness temperatures calculated from the analysis is shown above for CNTL (black) and AIRS (red)

- AIRS shows a positive improvement in correlation among all channels, with most notable improvement in sounder channels 1 (stratosphere CO_2), 2 (upper-troposphere CO_2) and 12 (upper troposphere H_2O_v)
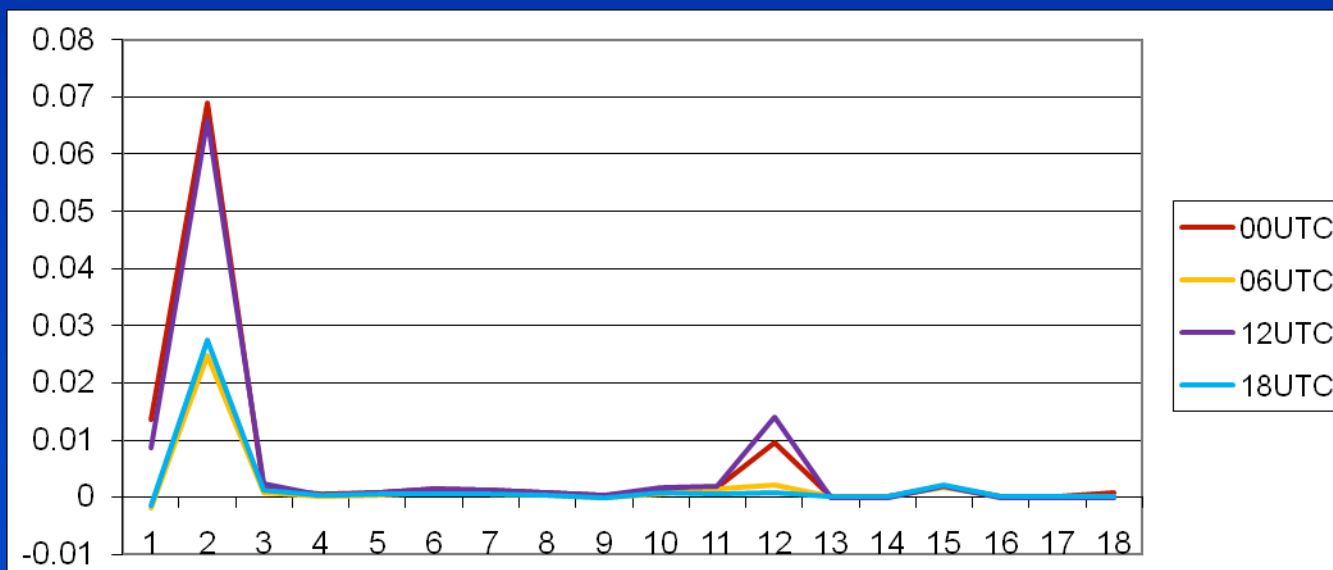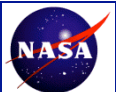
Analysis Verification

By Initialization Time

- When considering the difference in correlation between the AIRS and CNTL as a function of F00, it is seen that the 00 and 12 UTC analyses and 06 and 18 UTC analysis group together
  - At 00/12 UTC, AIRS measurements are directly coincident to GOES-11
  - At 06/18 UTC, AIRS measurements are over the eastern portion of the domain; Impact is thus from improved background field
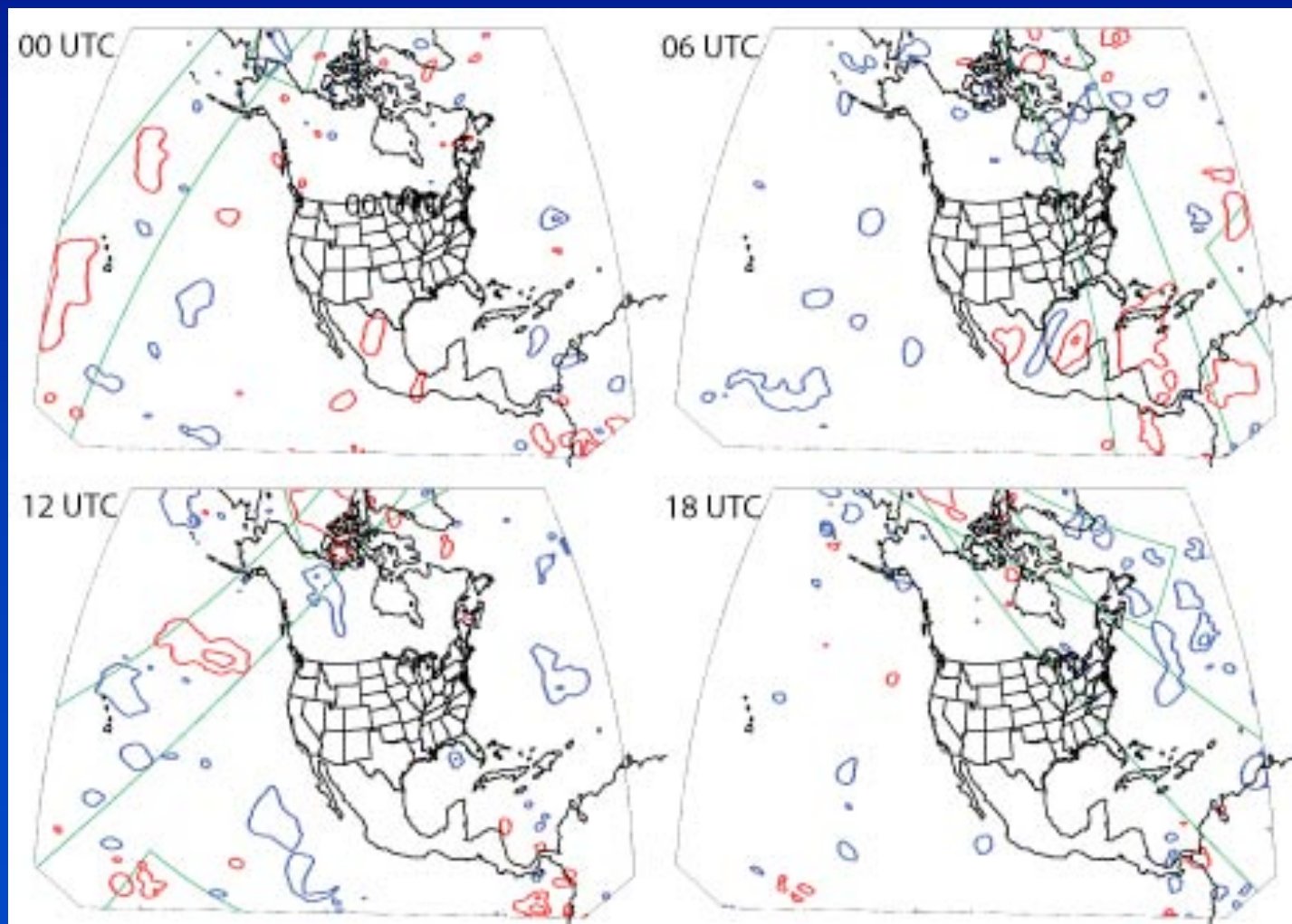
Analysis Impact

500 hPa Height Differences (9 Apr 2007)

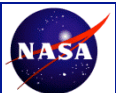5m, red – increase in height, blue – decrease in height

Forecast Verification

Limitations to Analysis Verification

- Verifying the analysis directly is problematic in two ways
    - Limited independent validation
    - The previous methodology, using GOES-11, involves a transformation to observation space
        - The GOES-11 T_b's view layer emission, not point observations. Thus, you're "viewing" broad layers of the atmosphere with contribution from many model levels
        - To a lesser extent, RT errors
- The solution to this is to <u>verify the forecasts</u>
    - An improved analysis will result in an improved forecast
- The forecasts spawned correspond to the analyses verified in the previous step
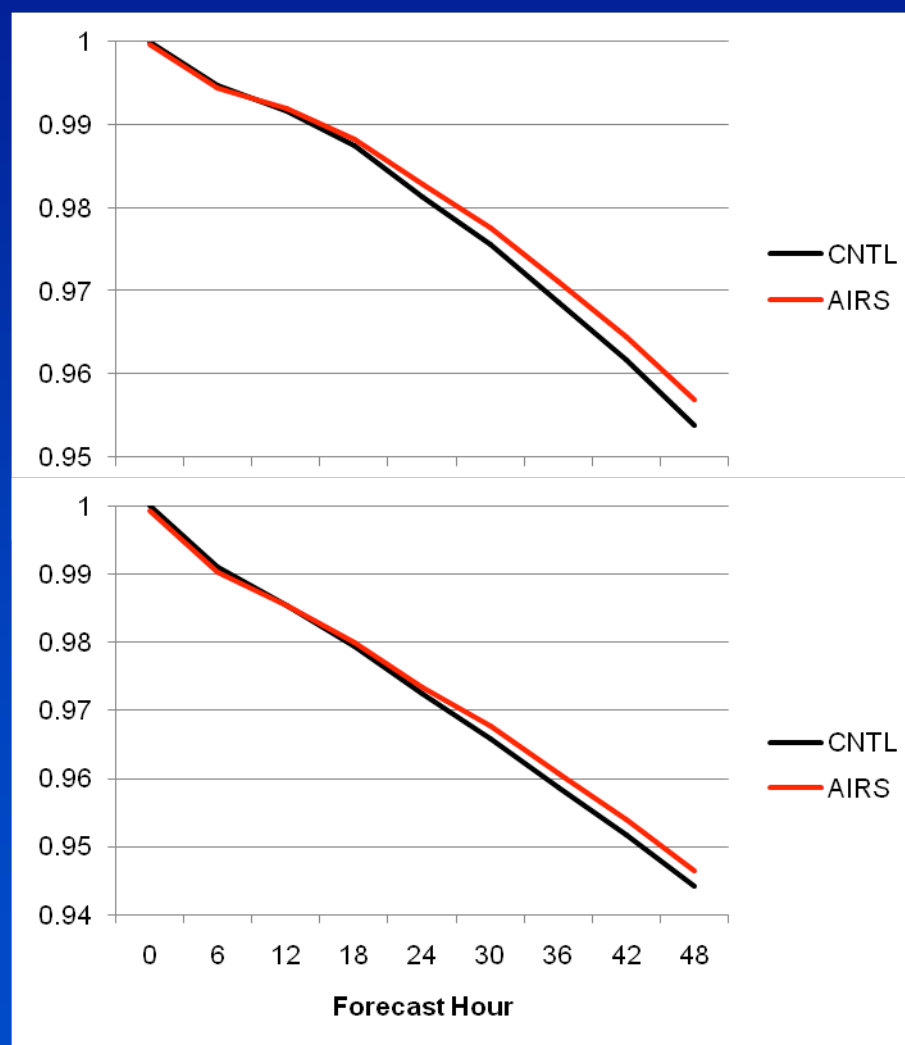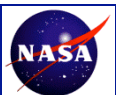
Forecast Verification

Height Anomalies

- A height anomaly is defined as

$$Z' = Z - \overline{Z}(\phi)$$

- Height anomaly correlations are calculated as the correlation between a forecast and a corresponding analysis

- To the left, 500 hPa (top) and 1000 hPa (bottom) height anomaly correlations over the CONUS are shown

- A forecast improvement of 2.4 hours at 500 hPa and 1.9 hours at 1000 hPa are seen at 48 hr
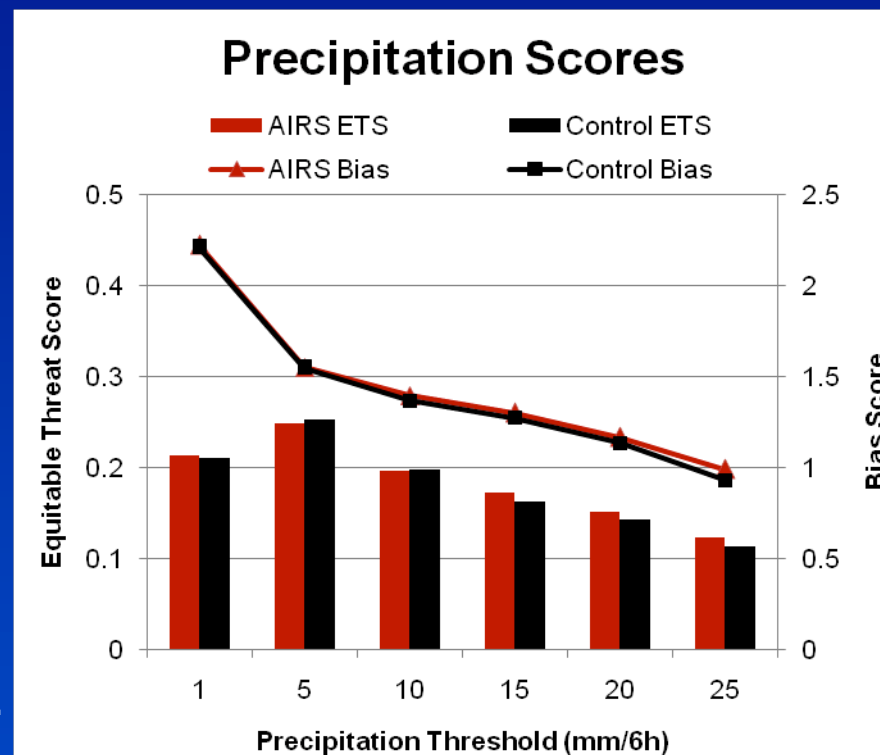
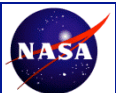
Forecast Verification

Precipitation Scores

- **Bias and Equitable Threat Scores (ETS) are shown**
  - **Bias indicates over- or under-forecasting**
  - **ETS is a ratio of success, where both successful forecasts and non-forecasts are considered**
  - **A "perfect" forecast will have a value of 1 for each score**
- **AIRS bias scores are comparable (< 5% improvement/degradation) to CNTL for all thresholds < 25mm/6h**
  - **Positive for the threshold of 25mm/6h, which shows a 7% improvement**

Precipitation Scores

- **ETS shows negligible impact for thresholds < 15mm/6h, but improvements of 6%, 6%, and 8% for the three thresholds ≥ 15mm/6h**
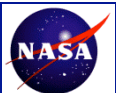
Conclusions

Impact of AIRS

- The addition of AIRS data to an NDAS-style system has shown to have a positive impact on analyses via comparison to GOES-11 observations
- Limitations of direct verification of the analyses are addressed with the verification of forecasts
- Forecast show a net positive improvement from the addition of AIRS data
- Cloud detection within the GSI (analysis) system may need further improvement, particularly in the Arctic regions, where cloud detection is difficult with infrared instruments
    - The cloud detection is instrument independent. In other words, cloud contamination of AIRS measurements is detected only using AIRS, no ancillary (i.e. visible) information is used
- Precipitation scores indicate that high-impact events, 25mm (~1 in) per six hours, are most significantly improved
- These results are promising with the recent launch of additional hyperspectral infrared sounders such as IASI and the future launch of CrIS

Earth Science Office
National Aeronautics and Space Administration

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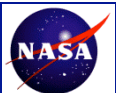**Shih-hung Chou, Gary Jedlovec, Bill Lapenta**
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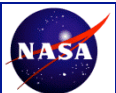**16 April 2008**

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Previous Results

• Using ADAS for analysis and initial condition production

• <u>Positive impact</u> on short-term WRF <u>temperature, moisture, and precipitation forecasts</u> at most forecast times with the assimilation of AIRS profiles

   • V4: November 2005 case study day

   • V5: January – February 2007 case study month

• Impact on forecast depends on case study, use of quality flags, assimilation time, and model resolution

• Decision to move from ADAS to the inherent WRF 3D variational scheme (WRF-Var)

Much of the work done since the last science team meeting has been in this transition
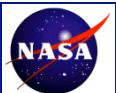
SP RT

Reasons for moving to WRF-Var

- ADAS not designed to produce dynamically-balanced momentum fields

  - results in 6+ hour spin-up time for WRF model

  - can produce unrealistic looking forecasts in first few hours

- A variational assimilation scheme is advantageous:

  - produces dynamically-balanced initial conditions

  - runs in parallel for quicker real-time runs

  - more widely accepted in DA community

- Use WRF-Var instead of GSI because of ease of compilation and relatively better documentation/support

Ongoing Work with WRF-Var

- <u>Generated background error covariances</u> for specific model domain, time of year, and background type

- Modified WRF-Var to allow assignment of <u>separate observation errors</u> for overland and overwater AIRS soundings

- <u>Tuning analysis</u> to ensure we have appropriate length scales for background error covariances and observations

- Rerun Jan. – Feb. 2007 month-long case study using WRF-Var and V5 profiles

- <u>Submit manuscript</u> detailing use of AIRS profiles and forecast results